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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

cc/min	cubic centimeter per minute	mm	millimeter
cfm	cubic foot per minute	μm	micrometer
°F	degree Fahrenheit	pct	percent
ft	foot	ppb	part per billion
ft^3	cubic foot	ppm	part per million
h	hour	ppt	part per trillion
mg/m^3	milligram per cubic meter	s	second
min	minute		

REDUCING RESPIRABLE DUST CONCENTRATIONS AT MINERAL PROCESSING FACILITIES USING TOTAL MILL VENTILATION SYSTEMS

By Andrew B. Cecala,[1] George W. Klinowski,[2] and Edward D. Thimons[3]

ABSTRACT

The U.S. Bureau of Mines has designed and evaluated total mill ventilation systems at two different mineral processing operations. Both systems have proven very effective at reducing respirable dust levels throughout the mill in a cost-effective manner. A 25,500-cfm system installed at a clay processing mill provided approximately 10 air changes per hour. This system reduced respirable dust concentrations by approximately 40 pct throughout the mill building. The second evaluation was performed at a silica sand operation. Tests were performed with 50,000 and 100,000 cfm of ventilation to the mill building, corresponding to 17 and 34 air changes per hour. Average mill-wide respirable dust reductions were 36 and 64 pct, respectively. Not only did these systems reduce respirable dust concentrations and increase visibility throughout the mills, they were also easy to install and required minimal maintenance. A total mill ventilation system provides a general purging of the mill air; the system should be viewed as a supplemental technique to assist other dust control systems in operation.

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BACKGROUND

The U.S. Bureau of Mines has been performing research on methods of lowering the dust exposure of workers at mineral processing operations for a number of years. This research has mainly been directed at source control techniques in an effort to lower a worker's dust exposure at a particular job function. In some cases, this control technology provided a carryover effect in lowering the exposure of workers at other locations, but for the most part the technology had very little effect in lowering dust levels throughout an entire mill building.

A recent Bureau study identified the various types of dust control techniques that were being used by the U.S. mining industry in coal preparation plants and mineral processing operations (*1*).[4] This work briefly evaluated the advantages and disadvantages of the following techniques: ventilation, baghouse-type collectors, wet scrubbers, electrostatic precipitators, source control, sprays, good housekeeping, and personal protection devices. Looking specifically at mineral processing operations, the authors' experience has indicated that baghouse-type collectors are the most common technique used by the industry. At the other extreme is ventilation, which is given little consideration by the industry.

Recently, the Bureau became aware of several mineral processing operations having problems with high overall mill dust levels. These operations were all using baghouse-type collectors to address their most serious dust contamination areas. Although these major dust sources were being controlled, there were numerous minor dust sources that were not. These minor dust sources were causing dust levels in these operations to gradually increase as the day or shift progressed. In some cases, dust concentrations continually rose for the entire shift (figure 1, case A). In other cases, dust levels would stabilize at a certain level as natural ventilation provided a purging of the structure (figure 1, case B).

These minor dust sources can be generated from numerous processes or events. Some sources are common throughout the industry, whereas others are site specific. Some common sources are product dropping off from the bottom of conveyor belts or being knocked off by the rollers on a conveyor line; product residue on walls, beams, and equipment becoming airborne from the vibration of the processes and equipment operating within the mill; product on walkways and access areas being generated as workers walk throughout the mill; product leakage from chutes or transfer points; leakage from dust control equipment; dust released or generated from improper housekeeping practices; and product released when inspecting screens or other milling processes when covers or lids are opened. Every effort should be made by plant managers to ensure that these dust sources listed, many of which are housekeeping practices, are continually addressed to minimize their effects.

A cost-effective supplemental dust control method to control a gradual increase in dust levels over the shift is to use a total mill ventilation system. During a Bureau survey of 25 coal prep plants, it was observed that those operations that effectively used some type of general ventilation system had the lowest overall dust concentrations (*2*).

One possible reason for the lack of general mill ventilation systems in the minerals processing industry is the shortage of published information addressing this area. The Industrial Ventilation Manual is the primary reference source on general plant ventilation systems in the United States (*3*). Although this manual is excellent for engineers doing plant design work and is quoted by some authors as "the Bible" in this area (*4*), there is no specific information provided on the proper design of total mill ventilation systems. Eshelman (*5*) took the information provided in the Industrial Ventilation Manual on general and localized exhaust systems, expanded it, and noted the importance of mill ventilation systems, but did not provide plant engineers the needed information to implement the technique. Because of the lack of published information and the limited use of general ventilation systems in the industry, the Bureau decided to perform a short-term study in this area. This research effort was performed in an effort to improve the health and safety of men and women working in mineral processing operations throughout the Nation.

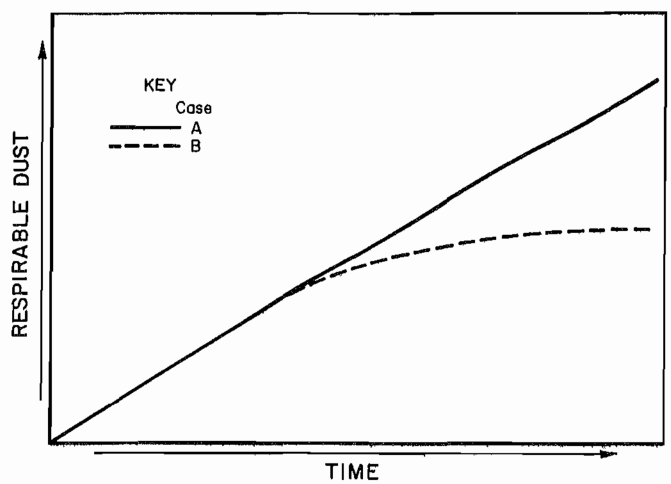

Figure 1.—Increases in total mill dust levels as day or shift progresses and dust sources are not addressed using control techniques.

[4]Italic numbers in parentheses refer to items in the list of references at the end of this report.

INTRODUCTION

The authors could not find published guidelines as to what ventilation volumes should be provided to mineral processing plants or mills. The Mine Safety and Health Administration (MSHA) uses 30 CFR 56.5005, which states that "control of employee exposure to harmful airborne contaminants shall be, insofar as feasible, by prevention of contamination, removal by exhaust ventilation, or by dilution with uncontaminated air." This general standard states that the use of exhaust ventilation is a possible technique to control employee exposure but does not give suggested guidelines for air volumes. The intent of the present study was to determine general guidelines and design criteria for operations that may be interested in implementing such a total mill ventilation system.

Most mill buildings can be considered closed systems, and thus any dust that is not being controlled within the structure will cause dust levels to gradually increase over the shift. A total mill ventilation system should be designed to draw clean makeup air in near the base of the mill. This air provides general purging and may clear some dust-laden areas throughout the mill structure. This air should be discharged at or near the top of the structure, where it will not contaminate plant personnel working outside. In addition, thermodynamic effects from heat generated by mill equipment will produce a chimney effect, thus assisting the basic flow pattern of this ventilation system. This technique should not present any environmental problems since the exit velocity and dust concentrations are relatively low. Without this exhaust system, dust can exit the building through open doors, windows, etc., and contaminate outside plant workers. This dust can also be recirculated back into the mill building, causing additional contamination problems. A total mill ventilation system is not a stand-alone technique, but is a supplemental technique to assist other localized dust control systems.

TESTING EQUIPMENT AND PROCEDURES

Total mill ventilation systems were evaluated at two different processing operations. For both of these field test sites, the primary goal was to determine the reduction in respirable dust concentrations throughout the structure. The respirable dust monitoring equipment and analysis were identical at both test sites, except for the actual location of the equipment. The evaluation was conducted by monitoring with and without the total mill ventilation system.

Dust sampling was performed using both gravimetric samplers and real-time aerosol dust monitors (RAM-1's). Both of these instruments were used with the 10-mm Dorr-Oliver cyclone to classify the respirable portion of dust, usually considered to have aerodynamic diameters of 10 μm or less.

Gravimetric dust samples were taken at most evaluation points. Gravimetric dust filters were weighed before and after use at the Bureau. This sampling procedure allows for a determination of the average respirable dust concentration over the entire time that the device was operated. Since the goal was to determine the change in dust levels with and without the total mill ventilation system, two sets of gravimetric samplers were used, one operating when the ventilation system was on and the second operating with the ventilation system off. In all cases, dust concentrations were determined by operating two or three sampling pumps side by side to determine an average concentration. Each gravimetric sampler provided one dust concentration value for each day of testing. Gravimetric sampling is the primary means for compliance sampling performed by MSHA for the mining industry.

RAM-1's located at all dust sampling locations were also used for testing. The RAM-1 is an instantaneous device that determines respirable dust concentrations by the light scatter of particles drawn through an internal sensing chamber by a sampling pump. This instrument has been used for many years in dust research and has proven to be a very reliable and accurate device. The RAM-1 was ideal for comparing the effectiveness of a total mill ventilation system in that it permitted respirable dust concentrations to be determined for short time segments throughout the evaluation.

MILL 1

TESTING

The first evaluation was performed at a clay processing facility in New York State. The general mill ventilation system was designed and installed at the crushing and screening mill. The base dimensions of this mill were 130 by 32 ft with a volumetric capacity of 150,000 ft^3. The total mill ventilation system was designed to provide 25,500 cfm of ventilation air to the mill, representing approximately 10 air changes per hour. This ventilation was provided by three 8,500-cfm roof powered exhaustors that were evenly spaced across the roof of the mill building (fig. 2). Each exhaustor was wired separately to permit repair of one unit while the other units remained functional. This also allowed plant personnel the flexibility to turn one or two units off during the winter months when outside air temperatures are low and could cause freeze-up problems. Three wall louvers were installed to provide an inlet for makeup air near the base of the mill. These louver locations were chosen to provide for minimal makeup air dust levels and a good distribution profile for the entire mill.

Five locations were monitored for dust concentrations in the mill building to provide a good dust profile (fig. 2). Sampling locations 1, 4, and 5 were near the screening process because of fluctuations at all three levels of the mill in this area. Sample location 2 was at a central main access way. Location 3 was at the other end of the mill building to establish the entire mill profile. Each monitoring location had both gravimetric sampling packages and a RAM-1. The analysis was performed by monitoring dust levels for 1-h periods with and without the total mill ventilation system.

Two evaluations were performed at this mill. The first was in December, when outside air temperatures ranged from 10° to 40° F. Only 2 days of testing were performed because of extremely high winds and mill freeze-up problems. Temperatures with the windchill factor dropped as low as -30° to -40° F during the first part of the shift. The second evaluation was in April, when outside air temperatures ranged between 50° and 80° F.

All monitors were placed in the same locations for both evaluations except for the monitor at location 5, which had to be moved from its original position in December to a nearby location in April because of an open door used to clean the area around the screens. This open door should not have affected the total mill ventilation system, but it would have biased the dust levels recorded by this monitor.

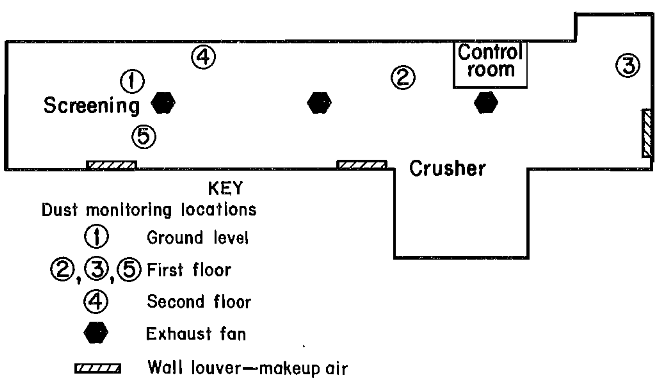

Figure 2.—Five dust monitoring locations at mill 1.

RESULTS

The 2 weeks of testing at this mill verified the effectiveness of the exhaust ventilation system in lowering respirable dust concentrations throughout the entire mill. Comparing the gravimetric sampler results, respirable dust concentrations ranged from 0.22 to 2.39 mg/m^3 with the ventilation system off, compared with 0.13 to 1.55 mg/m^3 with the ventilation system on for the December analysis. In April, respirable dust concentrations ranged from 0.29 to 4.84 mg/m^3 with the ventilation system off, compared with 0.21 to 2.37 mg/m^3 with the system on. Visibility throughout the mill building was greatly improved with the ventilation system in use, also indicating lower mill dust levels.

Table 1 lists the percent dust reductions for gravimetric and RAM-1 instruments at the five monitoring locations for both weeks of testing at mill 1. Each value was determined by comparing the average concentration with the ventilation system off and on for the entire day of monitoring. Although the correlation between the gravimetric and RAM-1 results on an individual location basis was less than expected, this was not the case for the overall average reduction for the results. The mean value and standard deviation for gravimetric and RAM-1 results were x = 42.5, s.d. = 17.6 and x = 37.1, s.d. = 16.8, respectively. Generally, the system reduced total mill respirable dust concentrations by approximately 40 pct. Figure 3 shows an approximate 3-h period recorded by the RAM-1 located at sample location 5 for day 2 of testing in December. The graph shows approximately 1-h periods with the system off, then on, and then off again. When the total mill ventilation system was started, it took approximately 8 to 10 min to get dust levels down to stabilized levels. Since the system was designed to provide 10 air changes per hour, 1 air change would occur every 6 min.

Figure 4 indicates the effectiveness of the total mill ventilation system at clearing a contaminant from the mill building. A smoke flare was released inside the mill at 8:50 a.m.; it took approximately 2 min to discharge. To contaminate the entire mill, the flare was constantly moved around on the ground level during this 2-min discharge period. The graph indicates the contaminant level recorded by the RAM-1 at location 2 during this simulated contaminant test. It took 8 to 10 min to get the contaminant cleared from the mill. This result corresponds with the time period necessary for respirable dust levels to stabilize after the ventilation system was turned on under normal test conditions, as previously mentioned.

Table 1.—Dust reduction for gravimetric and RAM-1 instruments at five monitoring locations for both field evaluations at mill 1, percent

Day	1		2		3		4		5	
	Gravimetric	RAM-1	Gravimetric	RAM-1	Gravimetric	RAM-1	Gravimetric	RAM-1	Gravimetric	RAM-1
DECEMBER 1989										
1	64.9	54.8	33.3	18.5	40.7	55.0	55.0	53.4	33.5	(1)
2	49.0	18.4	54.2	43.8	40.9	35.0	67.4	55.3	(1)	72.5
APRIL 1990										
3	37.4	20.1	66.7	53.5	14.6	22.7	48.7	38.2	53.4	12.1
4	63.3	44.3	27.7	46.3	0	33.3	27.6	37.2	44.8	29.5
5	48.3	16.8	63.5	56.9	27.3	26.2	39.5	35.9	19.2	9.9

[1]Equipment malfunctioned.

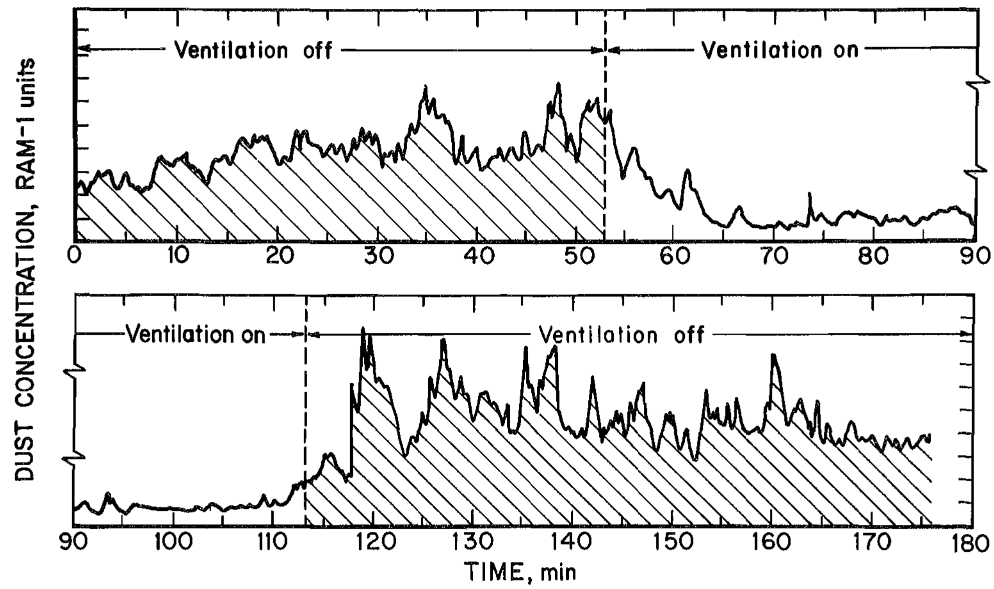

Figure 3.—Respirable dust levels at location 5 with and without total mill ventilation system.

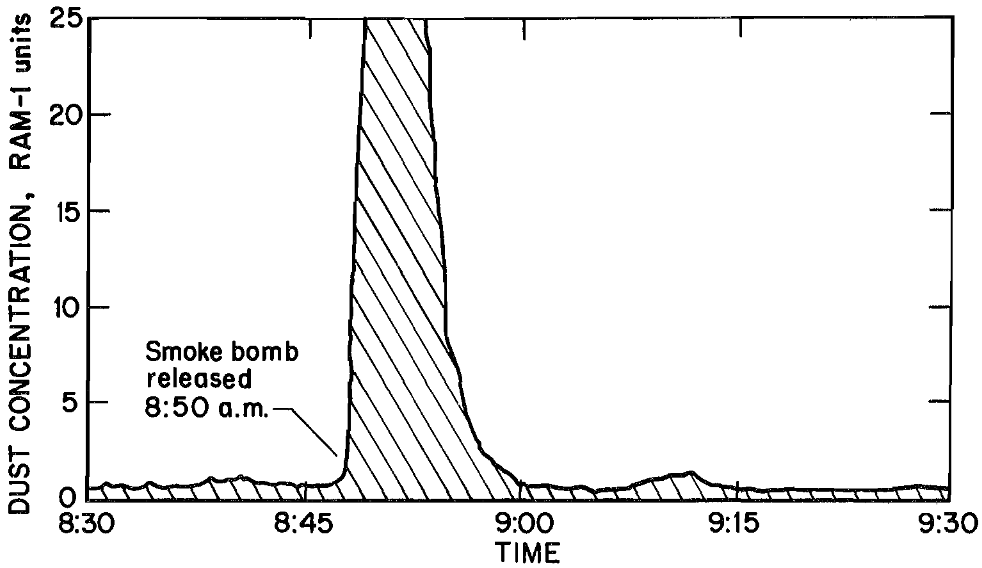

Figure 4.—Effectiveness of total mill ventilation system at removing smoke from mill building.

MILL 2

TESTING

The second evaluation was performed at a silica sand operation in central Texas for two 14-h days of testing. The mill was a six-story structure located on three-story storage silos. The structure was 79 ft high, with base dimensions of 66 by 34 ft, having a volumetric capacity of 177,000 ft^3. The system was composed of four 25,000-cfm belt-driven propeller-type wall exhaustors providing 100,000 cfm of ventilation to the mill building, corresponding to about 34 air changes per hour. One fan was located on the top outside wall on each side of the building. These fans were designated as north, south, east, and west fans. Each fan was separately wired to the control room. Some tests were performed with only two fans operating (east and west sides of the building), providing approximately 17 air changes per hour.

Since there were a number of large doors at the base of this mill, there was no need to install additional inlets for incoming makeup air. These doors remained open at all times during testing. There was also a bank of windows between levels A and B of the building that mill workers liked to keep open. These windows were closed during all testing except for one test sequence conducted to determine the effects of opening them.

There were six dust monitoring locations inside the mill building (fig. 5). RAM-1 instruments were placed at all locations. Gravimetric samples were located on the south side of the building at sample locations 2, 4, and 6, corresponding to levels A, B, and C, respectively.

Continuous monitoring digital thermometers were located at levels A, B, and C inside the mill building to examine changes in temperature due to the total mill ventilation system. This operation is located in central Texas and temperatures rise to high levels in the summer months. Also, the equipment, motors, etc., located inside the mill building generate a substantial amount of heat. Both of these factors contribute to high temperatures inside the structure in summer months. If the total mill ventilation system cooled the structure, this would be an additional benefit.

RESULTS

The results of testing at this operation showed the effectiveness of the ventilation system at reducing respirable dust levels while providing a slight general cooling. Testing also confirmed that the effectiveness of the general ventilation system was reduced in the bottom of the structure when the windows were open.

Table 2 shows results with RAM-1's for both days of testing at five monitoring locations. The RAM-1 instrument at location 5 malfunctioned, and no valid information was obtained for this location. Table 3 lists the results for the gravimetric samplers at monitoring locations 2, 4, and 6.

The reduction in respirable dust concentrations with the ventilation system ranged from 47 to 74 pct as recorded by the RAM-1's. For the gravimetric samplers, this reduction ranged from 60 to 86 pct. When only two exhaust fans were used (east and west sides of building), the respirable dust reduction recorded by the RAM-1's ranged from 6 to 55 pct, as compared with 25 to 78 pct for the gravimetric samplers.

Using the RAM-1 results, the average respirable mill dust concentration with no fans was 2.66 mg/m^3. The average concentrations with two and four fans were 1.7 and 0.95 mg/m^3, respectively. This corresponds to average reductions for all five dust monitoring locations of 36.1 and 64.3 pct, respectively. The effectiveness of the total mill ventilation system can be seen in figure 6, which indicates the percent reduction in respirable dust levels for both days of testing with both two and four fans.

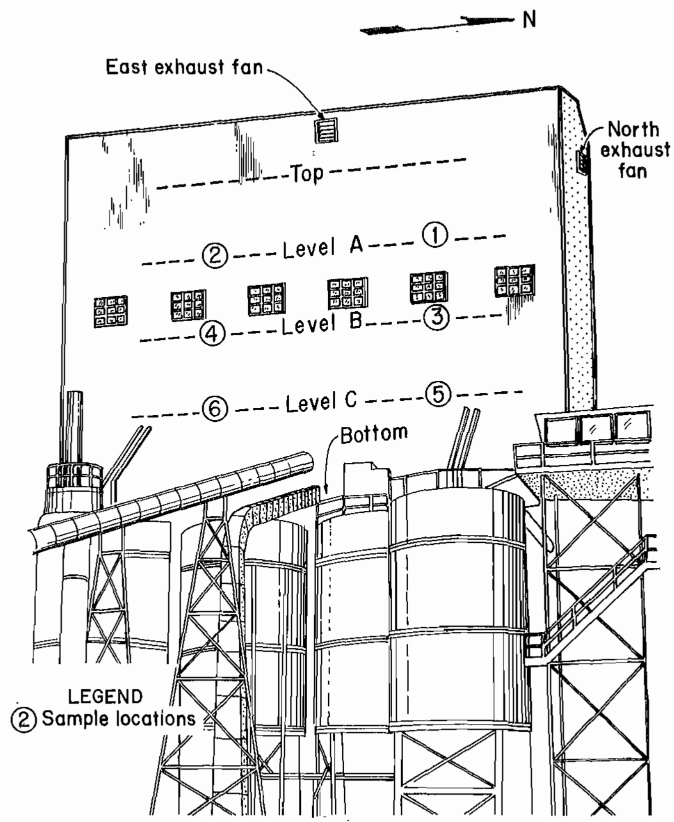

Figure 5.—Six dust monitoring locations at mill 2.

Table 2.—Dust concentration and percent reduction for RAM-1 instruments at five monitoring locations at mill 2

Location	Fan off concentration, mg/m³	2 fans Concentration, mg/m³	2 fans Reduction, pct	4 fans Concentration, mg/m³	4 fans Reduction, pct	4 fans, windows open Concentration, mg/m³	4 fans, windows open Reduction, pct
DAY 1							
1	2.17	1.17	46.08	0.88	59.45	(1)	(1)
2	2.53	2.39	5.53	1.35	46.64	(1)	(1)
3	2.36	1.43	39.41	.85	63.98	(1)	(1)
4	2.04	.92	54.90	.71	65.20	(1)	(1)
6	1.92	1.16	39.58	.89	53.65	(1)	(1)
DAY 2							
1	2.59	1.69	34.75	1.06	59.07	1.02	60.62
2	3.67	2.10	42.78	1.18	67.85	1.18	67.85
3	3.31	2.13	35.65	.97	70.70	1.35	59.22
4	3.68	2.46	33.15	1.02	72.28	1.68	54.35
6	2.32	1.58	31.90	.61	73.71	1.48	36.21

[1]No testing performed.

Table 3.—Reduction of respirable dust levels with gravimetric samplers at three monitoring locations at mill 2, percent

Number of fans	Level A, location 2	Level B, location 4	Level C, location 6
DAY 1			
2	24.8	56.4	45.6
4	70.5	72.6	59.5
DAY 2			
2	54.9	52.4	77.5
4	76.9	80.5	86.4

Figure 7 shows the temperature readings at three levels in the structure for day 1 of testing. One can determine when the exhaust fans were or were not in use by looking at the direction of temperature values at the three monitoring locations. With no exhaust fans, the temperature levels rose; when the ventilation system was used, the temperature readings decreased.

The ventilation system was less effective in the bottom of the structure when the windows were open. During day 2 of testing, the windows were opened for 1 h between 4:10 and 5:10 p.m. with all four fans in operation. The lack of ventilation on level C of the building was obvious

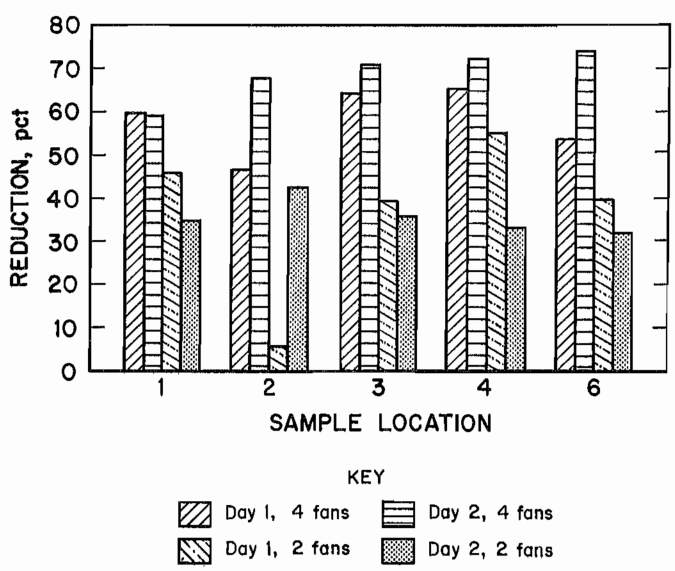

Figure 6.—Percent reduction of respirable dust at each monitoring location for 2 days of testing for both two and four fans using RAM-1 devices.

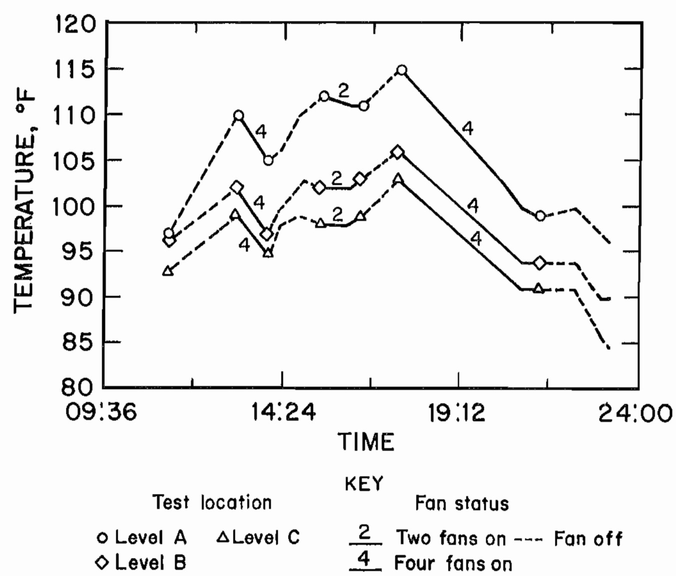

Figure 7.—Temperature readings at three levels in mill building during day 1 of testing with and without total mill ventilation system.

from both dust and temperature levels. At location 6, on level C of the building, the RAM-1 recorded an average respirable dust concentration of 0.61 mg/m^3 with the windows closed, compared with 1.48 mg/m^3 with the windows opened. The only time the temperatures on level C exceeded temperatures on levels A and B was when the windows were open. Makeup air was mainly being drawn into the mill from the open windows, making the ventilation system ineffective in the bottom portion of the structure. The windows should remain closed if the ventilation system is used.

TRACER GAS ANALYSIS

A tracer gas study was also performed at mill 2 to analyze the effectiveness of the total mill ventilation system. Sulfur hexafluoride (SF_6), the tracer gas used in this analysis, is a colorless, odorless, nontoxic, inert gas not normally found in the environment and detectable at concentrations in the parts-per-trillion range. A similar study was recently performed by the Canada Centre for Mineral and Energy Technology in Elliot Lake, Ontario, Canada, to determine ventilation patterns in a fluorspar milling plant (*6*).

For this analysis, the SF_6 tracer gas was released from a small lecture cylinder at a rate of 5.0 cc/min. Six different tests were performed using the tracer gas. For tests 1 through 4, the gas was released by a person moving the tracer gas release cylinder around on the bottom floor of the mill to provide good dispersion throughout the bottom of the structure. For tests 5 and 6, the tracer gas was released from a single point at the center of the building on the bottom floor. For all six tests, the tracer gas was released for several minutes before the first air sample was taken and then was released for a predetermined time afterward.

Gas samples were taken at the various exhaust fans at the top of the mill structure using disposable plastic syringes (fig. 8). Each syringe was numbered and labeled with test number, location, and time. Sampling rates varied from every 30 s to every 2 min. After a test was completed, the samples were analyzed on-site using electron-capture gas chromatography. This portable chromatograph was capable of detecting SF_6 from 50 ppt to 5 ppm. This chromatograph was a prototype unit built by the Canada Centre for Mineral and Energy Technology in Sydney, Nova Scotia, Canada. The chromatograph was calibrated on site to ensure an accurate analysis.

Four tests were conducted to compare the changes in tracer gas levels with two versus four fans operating. Tests 1 and 3 were performed with four fans operating and had similar results. Tests 2 and 4 were performed with two fans and were also similar. Figure 9 shows a comparison of concentrations recorded at the various fan locations for tests 3 and 4. Two points should be noted. The first is that the tracer gas was cleared from the structure much faster with all four fans operating. In this case, the tracer gas was significantly removed from the structure at the 5-min mark; with only two fans operating, the gas was evident until approximately the 8-min mark.

The second point is that the tracer gas was being drawn from the east and west fans much more effectively than from the north fan. The maximum concentration recorded at the north fan was 80 ppb, compared with concentrations of over 300 ppb at both the east and west fans for test 3. It appears that the east and west fans were more effective in ventilating the mill than the north fan was.

Tests 5 and 6 were run to compare the effectiveness of the ventilation system with the windows in the structure closed versus open. Figure 10 shows the tracer gas concentration measured at the east fan for these two tests. The findings support the dust and temperature results. With the windows closed, the contaminant was cleared from the mill faster than when the windows were opened.

Figure 8.—Worker taking gas sample for tracer gas analysis at exhaust fan.

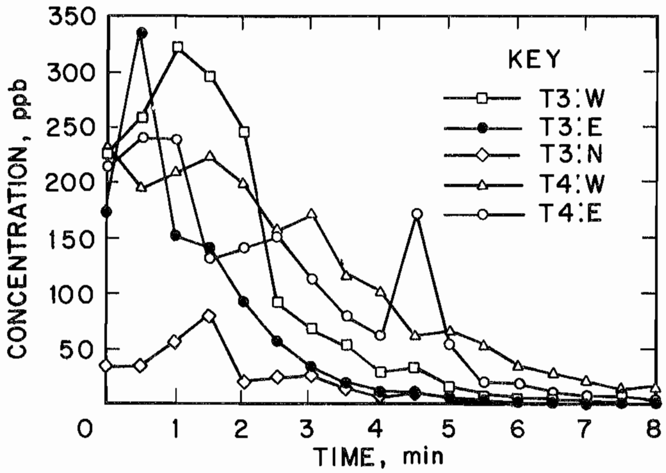

Figure 9.—SF_6 analysis—comparing four fans (T3) versus two fans (T4) for total mill ventilation system. W, concentration recorded at west fan; E, concentration measured at east fan; N, concentration recorded at north fan.

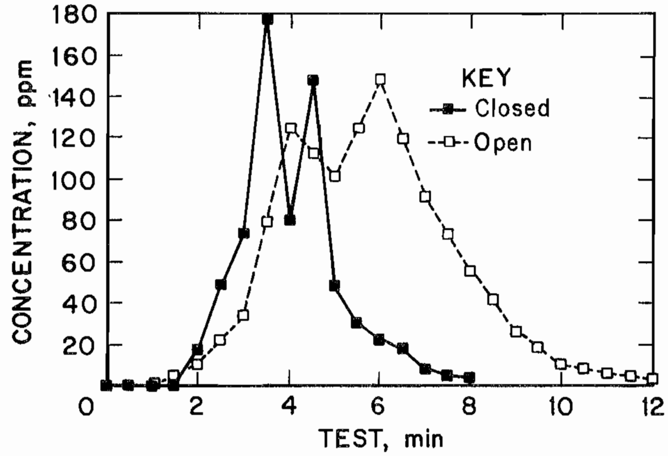

Figure 10.—SF_6 analysis—effectiveness of total mill ventilation system with windows open versus closed. Concentrations recorded at east fan.

DISCUSSION

One goal of this research effort was to develop a ventilation profile and approximate the optimal size for a total mill ventilation system. This was not successful. Numerous engineering contractors who design coal preparation plants suggested that an exhaust ventilation system should provide between 8 and 12 air changes per hour. This value was used to size the ventilation system at mill 1 to provide 10 air changes per hour. After this evaluation, although the dust reductions achieved were very acceptable, there was no way to determine that this was the optimal size and that additional reductions could not be achieved with increased ventilation. The testing and evaluation plan for mill 2 was designed to determine this. The investigators believed that having a system capable of providing up to 34 air changes per hour would allow estimation of an approximate optimal operating point. By having a number of points on a ventilation profile curve, the approximate optimal size could be determined, as shown theoretically in figure 11*A*. The curve would be linear up to an area where it would start to flatten out. This area of flattening out would be the optimal ventilation volume. As the ventilation volume continues to increase past this point, it is theorized that the curve may start to show a decrease in efficiency as the total mill ventilation system starts to overpower other dust control techniques in the structure, such as baghouse-type collectors.

At mill 2, it was anticipated that the four fans would allow for a calculation of a ventilation profile curve. Two things prevented this. First, with all four fans operating, it appeared that the ventilation profile was still in the linear portion of the curve (fig. 11*B*). Second, there appeared to be a substantial difference between the efficiency of the east and west fans and the north fan as determined from the tracer gas testing. The south fan was not even tested because of manpower limitations during

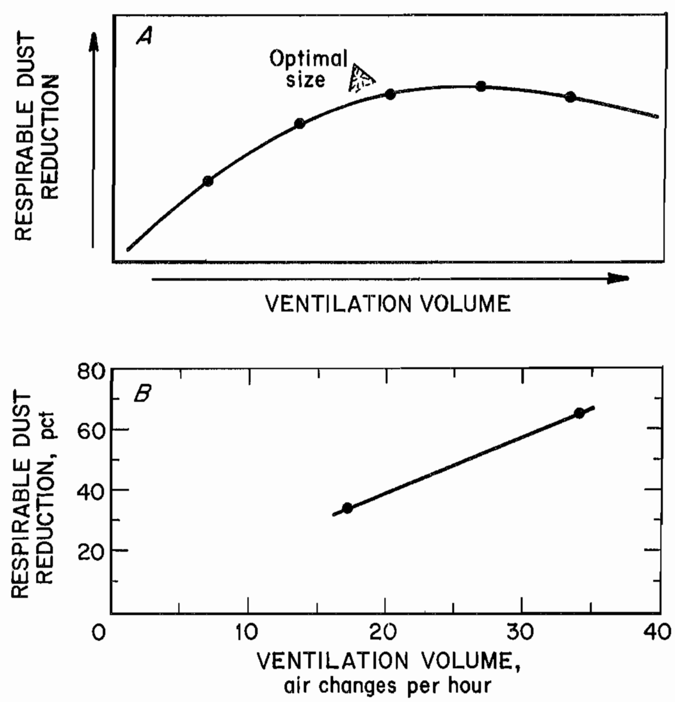

Figure 11.—Ventilation profile curves. *A*, Theorized ventilation profile curve with total mill ventilation system; *B*, ventilation profile curve for mill 2.

the evaluation and because it faced the primary direction of the prevailing wind at this operation. The ideal setup, in hindsight, would have been to have two fans on both the east and west sides of the building.

It would appear from all this that the optimal ventilation volume may vary substantially from structure to structure and may be higher than originally anticipated at some operations.

For a mill exhaust ventilation system to be effective, there are three design criteria that must be achieved. First, the system should be capable of supplying clean makeup air to the base of the mill. Contaminated makeup air will cause the ventilation system to increase dust concentrations and worker exposures. This was seen in a previous Bureau study, in which an inside bag operator was exposed to dust generated during bulk loading of trailer trucks outside the mill building. By controlling where the intake air is brought into a structure, using either wall louvers positioned at strategic locations at the base of the mill or other mill openings including doors, etc., dust-free makeup air can be brought into the mill.

The second design criteria is that the system should provide an effective flow pattern to ventilate the entire mill while providing a sweeping action in the major dust generation areas. This is achieved by the proper positioning of both the fans and makeup air intakes. The location of air intakes are then twofold in purpose: (1) to provide clean outside air and (2) to provide the most effective flow pattern to purge the entire inside of the structure.

The third design criteria is that the outer shell of the structure should be competent. An exhaust ventilation system draws makeup air into the structure from the point(s) of least resistance. A fan creates a pressure differential, causing a negative pressure inside the building. Air at a higher pressure outside the structure flows into the mill building to compensate for this pressure differential at the point(s) of least resistance. If the point(s) of least resistance are open or broken windows, holes or cracks in the wall or roof, or any opening in the vicinity of the exhaust fan(s), the designed ventilation flow pattern will be short circuited, causing the system to be ineffective. Mill 2 clearly shows this problem. When the windows halfway up the structure were open, the ventilation system was basically only working in the top portion of the structure.

Another consideration when designing a total mill ventilation system is to take into account prevailing wind direction. Wind direction would have a minor effect when using roof exhaustors as in mill 1, but it should be considered when using wall-type exhaustors, as used in mill 2. With wall exhaustors, fans should not be placed where the prevailing wind will work against them. Where possible, the fan should exhaust with the direction of the prevailing wind. This also minimizes the possibility of recirculation or reentrainment of dust back into the structure. Variability in the wind direction and speed should be taken into account, and the system should be designed to compensate for times when it will operate against the wind.

Total mill ventilation systems also pose possible freeze-up problems during winter months when extremely low outside air temperatures occur. There are a number of options that may be considered if this is a concern. One option is to heat the supply air coming into the mill building. If this is necessary, it will significantly increase the cost of using this technique. A second option is to back the system down by turning off some of the fans in a multifan system. However, in some cases, the ventilation system may not really impact freeze-up problems. Mill freeze-up problems were encountered during the first week of testing at the first evaluation site, but it appeared that the total mill ventilation system had little effect on them. As previously stated, this operation was in central New York State, where extremely low temperatures are encountered several months of the year. There was no designed heating of the mill building, and the only heating that occurred was from the motors, equipment, and processes being performed within the mill. Air temperatures were similar inside and outside the building with or without the total mill ventilation system in operation. Most freeze-up problems occurred through the night, when both the mill and the ventilation system were shut down. This system has been in operation for over 2 years with no evidence of increased mill freeze-up problems.

Additionally, a total mill ventilation system must be looked at from an environmental standpoint. The Environmental Protection Agency has four categories of compliance for crushed stone industry with the passage of the Clean Air Act. These four areas are process weight, fugitive, ambient, and permits concerns. At both of the evaluation sites in this study, each of the Federal standards were complied with. Visual examination of the exhaustors from outside showed no dust plume evident. The dust being exhausted was quickly diluted with atmospheric air, reducing its potential as a contaminant to the environment or to outside personnel. Measurements taken periodically at the base of the mill using handheld instruments at both evaluation sites did not indicate any increase in dust levels. One would need to consider any State regulations that may be more stringent than the Federal standards.

The total mill ventilation system is probably the most cost-effective method that an operation could consider to lower total mill dust levels. At mill 1, the total cost of the ventilation system, installation and materials, was approximately $10,000; this included having an outside contractor perform the installation work. At mill 2, the total cost of the system was approximately $6,000. The four fans each cost $880. Since these fans were placed on the walls of the structure, the work was easily done by the maintenance crew. Considering the respirable dust reductions obtained, no other engineering control technique available can yield these reductions for the cost. Not only are initial costs of this technique small, but operating and maintenance costs are also minimal.

CONCLUSIONS

The results of the field evaluations of the total mill ventilation system clearly indicate that this technique has potential application throughout the minerals processing industry. A 40-pct reduction in respirable dust was measured at the first evaluation site at a cost of only $10,000. An average 64-pct reduction was recorded at the second site at a cost of approximately $6,000.

The system uses dust-free outside air brought in at the base of the mill to sweep and clear contaminated areas, then discharges this air out of the top of the structure. Since the volume of ventilating air is minor relative to the size of the structure, the discharge air does not pose any contamination hazards to outside plant workers or the environment.

If wall-type exhaustors are used near the top of the structure, as with mill 2, the system should operate with the prevailing wind direction. There is always variability in the wind, which should be taken into account; the system should be designed to compensate for this. It must also be noted that in some cases, the total mill ventilation system may accelerate mill freeze-up problems. Operations could heat the supply air or back down the ventilation volume when air temperatures drop to levels that may cause freeze-up problems, as previously discussed.

If dust control techniques presently available to the industry are compared on a cost-benefit basis, total mill ventilation ranks near, if not at, the top of the list. However, the authors' experience shows it is an infrequently used technique. Considering the cost awareness of the industry and the new pending respirable dust standards that may establish the Threshold Limit Value at 5.0 mg/m^3 respirable limit for all metal-nonmetal operations, total mill ventilation is a technique that deserves industry attention.

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